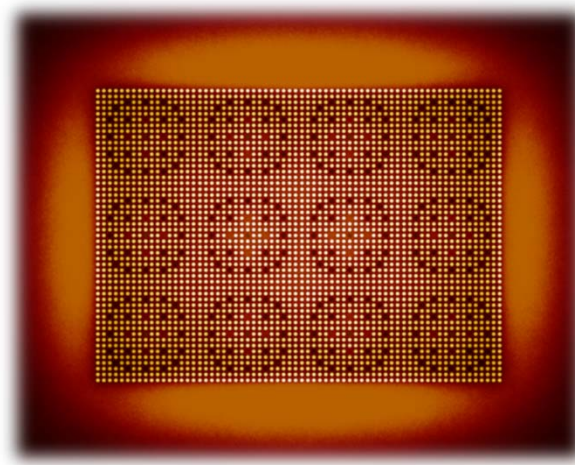


# Development of an object-oriented Serpent2-SUBCHANFLOW coupling and verification with Problem 6 of the VERA core physics benchmark

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# Presentation Overview

- Introduction & motivation
- McSAFE: high-fidelity multiphysics
- Serpent2-SUBCHANFLOW coupling
- Mesh-based feedback exchange
- Verification with Problem 6 of the VERA benchmark
- Conclusions & further work

# 1 – Introduction & motivation

- **Increasing effort** to develop highly accurate multi-physics approaches for nuclear reactor analysis of complex phenomenology.
- **Increasing demand** from designers, operators, regulators and other stakeholders.
- Several projects around the world oriented to provide **high-fidelity results** → improvement of local phenomena calculation & provide reference solutions).
- Under this framework, the **McSAFE** project started in 2017 under Horizon 2020 (EU):



**McSAFE: High –Performance Montecarlo Methods for SAFETY Demonstration:**

- ✓ **Cooperation** between code developers, methods developers and industry stakeholders.
- ✓ **12 partners from 9 countries** around EU and an extended community of users around world.

## 2 – McSAFE: high-fidelity multiphysics

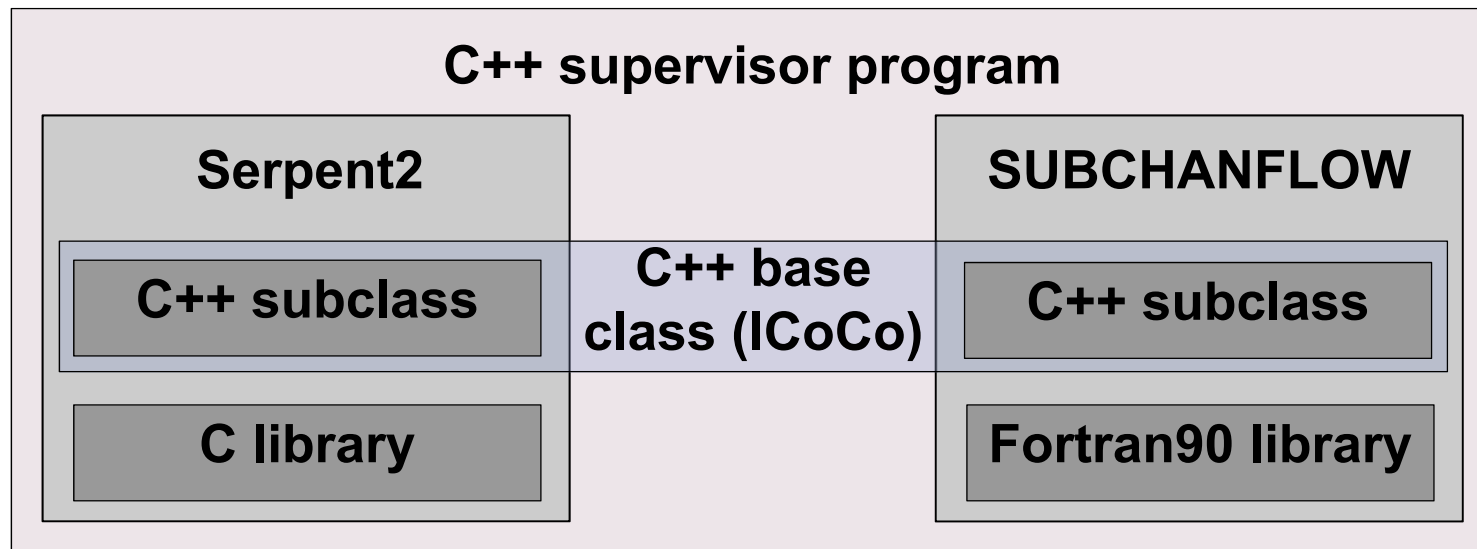
- Move towards high fidelity multi-physics calculations using advanced codes and methodologies.
- High performance Monte Carlo (MC) codes to become valuable tools for core design, safety analysis and industry like applications for LWRs of gen II and III.
- **Final scope:** NPP core level calculations including depletion and TH-feedback in a full scope approach (i.e. pin level):



***Develop a Serpent2-SUBCHANFLOW coupling scheme to be used in pin-by-pin steady-state and depletion calculations (towards full-core)***

### 3 – Serpent2-SUBCHANFLOW coupling

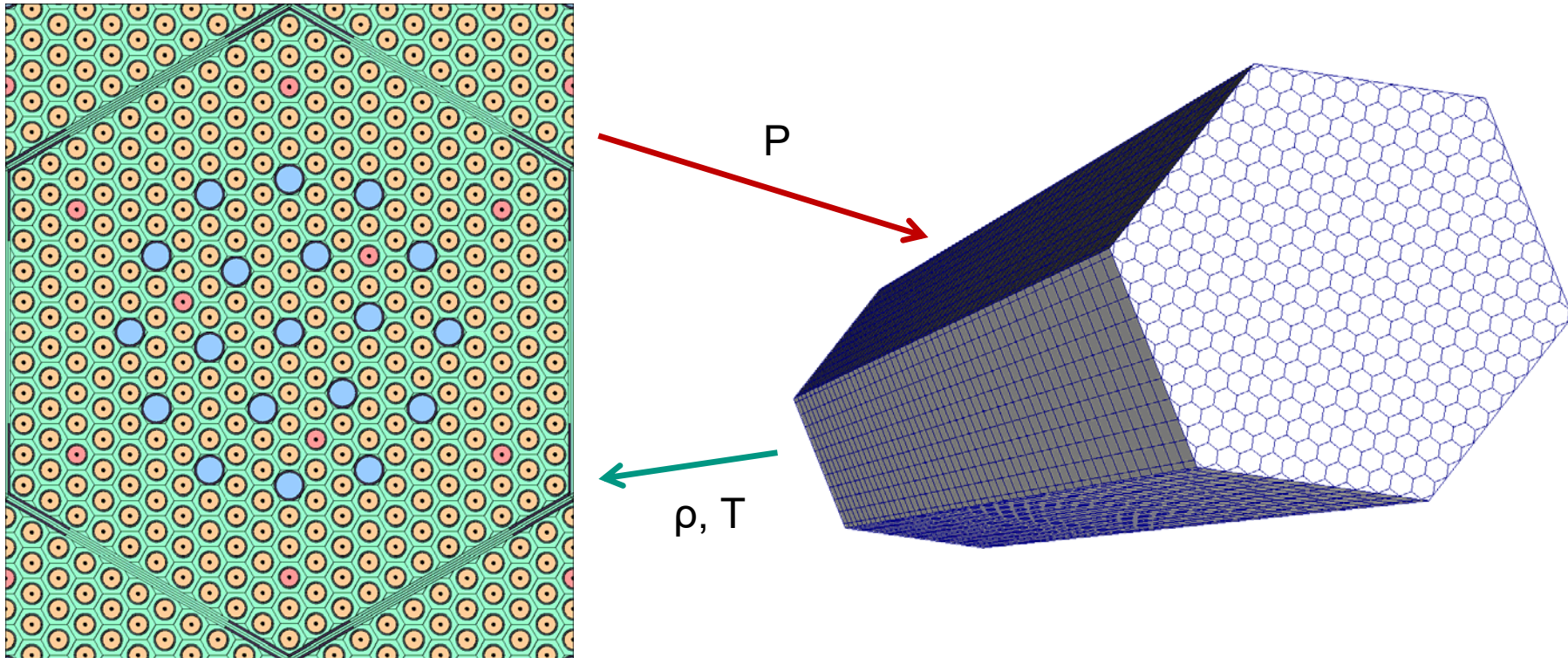
- Serpent2: continuous-energy Monte Carlo particle transport.
- SUBCHANFLOW: COBRA-based subchannel thermalhydraulics.
- Object-oriented design:



- Problem base class (ICoCo): generic multiphysics interface.
- Enhanced flexibility, maintainability and code reusability.
- Experimental implementation strategy.
- Backup strategy: master-slave coupling (proven, reliable and efficient).

## 4 – Mesh-based feedback exchange (1)

- Serpent2:
  - Multiphysics interfaces based on superimposing meshes on the tracking geometry to set densities and temperatures and get power.
  - Internal (nested) meshes represented as (MEDCoupling) unstructured meshes for feedback exchange and interpolation.

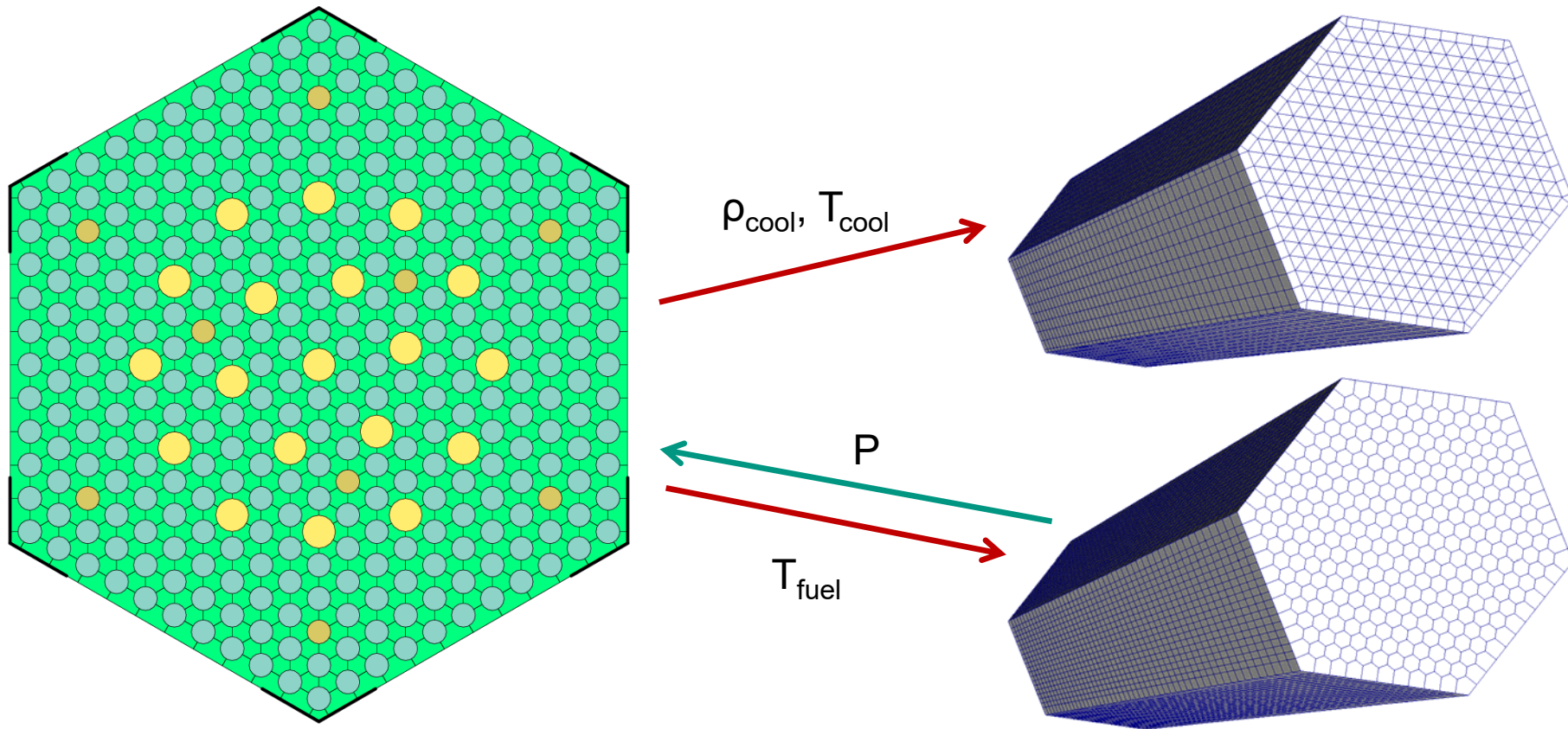




## 4 – Mesh-based feedback exchange (2)

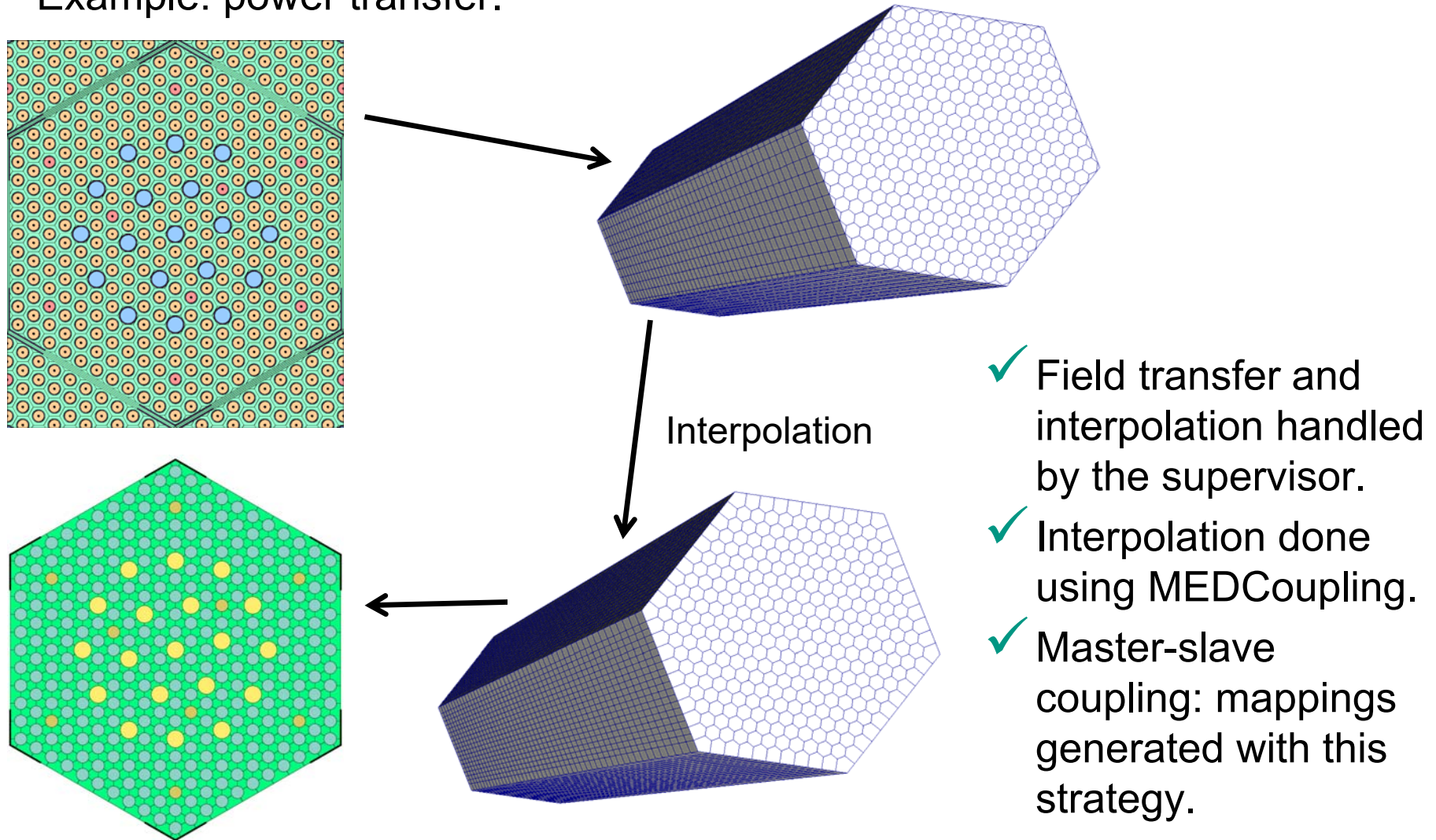
### ■ SUBCHANFLOW:

- Subchannel model defined by hydraulic parameters and connectivity.
- Coolant and fuel (MEDCoupling) unstructured meshes define the channel and rod geometry for feedback exchange and interpolation.



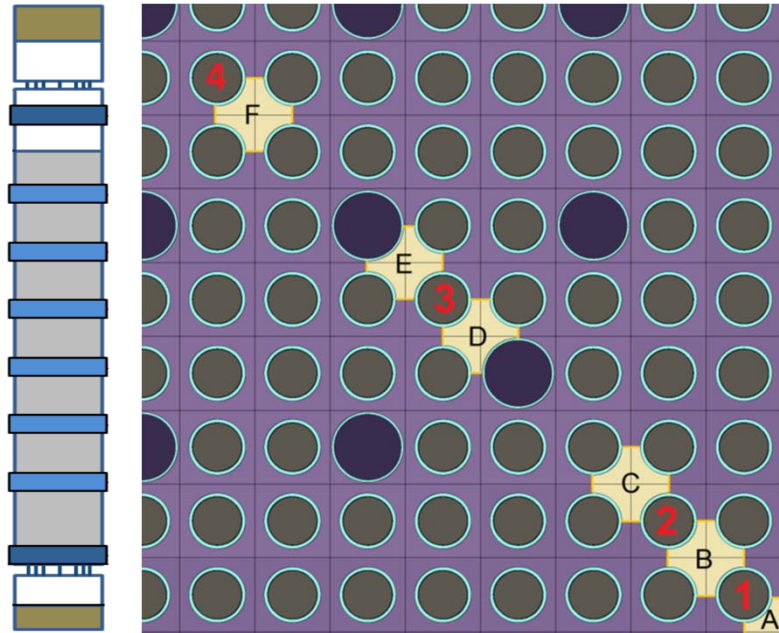
## 4 – Mesh-based feedback exchange (3)

- Example: power transfer.





# 5 – Verification with VERA - Problem 6 (1)

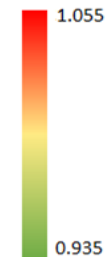


## ■ Multiplication factor:

Result	Keff	$\Delta K_{eff}$ (pcm)
VERA-CS	1.16361	-
RMC-CTF	1.16239 $\pm$ 0.00010	-90
MC21-CTF	1.16424 $\pm$ 0.00003	47
MCNP6-CTF	1.16500 $\pm$ 0.00006	103
Serpent2-SCF (OO)	1.16552 $\pm$ 0.00003	141
Serpent2-SCF (MS)	1.16560 $\pm$ 0.00003	147

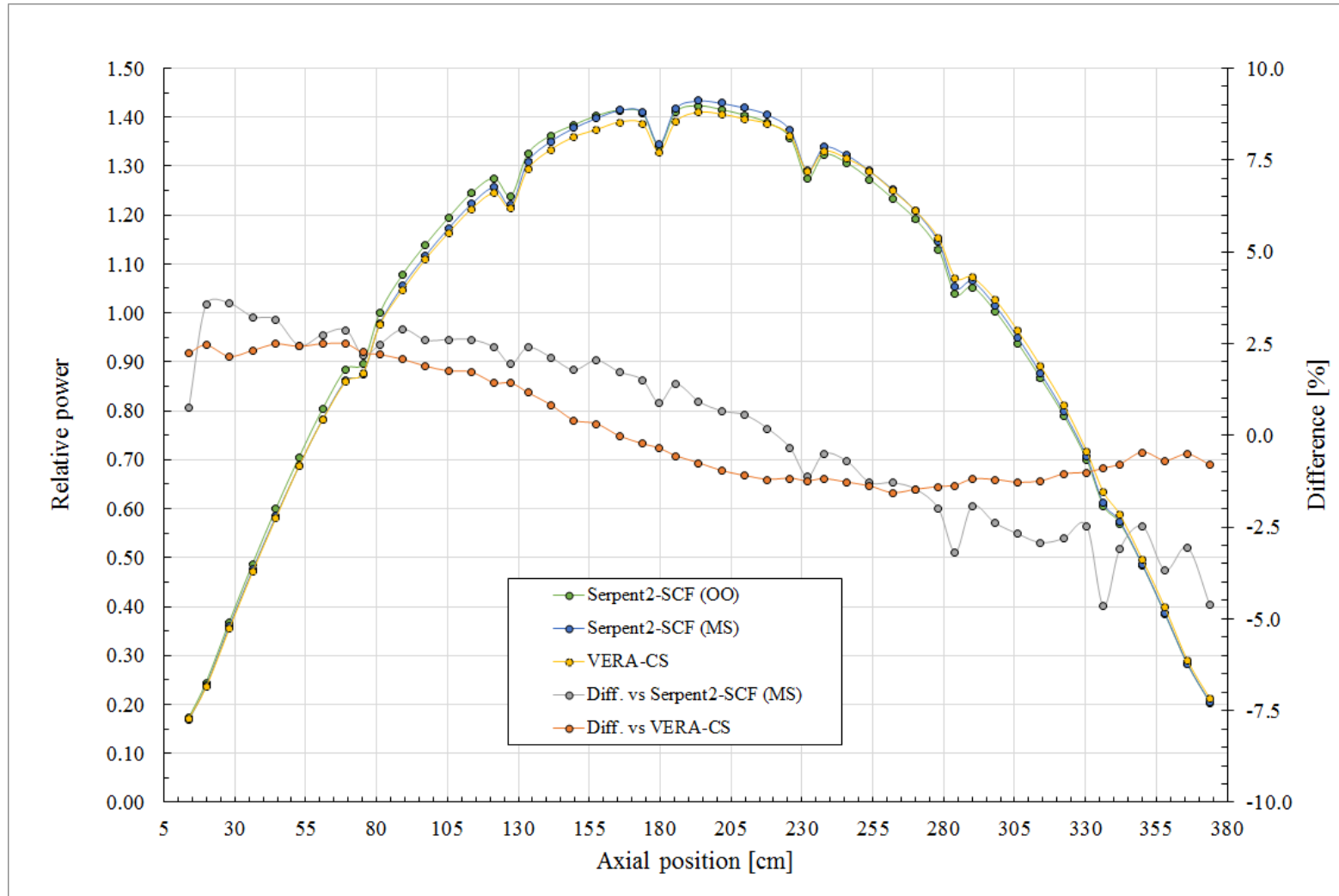
## ■ Pin-wise power, integrated axially:

	1.0355	1.0357		1.0342	1.0311		1.0114	0.9764	VERA-CS
	1.0345	1.0348		1.0335	1.0303		1.0112	0.9781	Serpent2-SCF (OO)
	-0.0010	-0.0009		-0.0007	-0.0008		-0.0002	0.0017	Diff. vs VERA-CS
1.0355	1.0096	1.0100	1.0359	1.0088	1.0057	1.0252	0.9890	0.9730	
1.0334	1.0077	1.0076	1.0355	1.0070	1.0045	1.0240	0.9873	0.9748	
-0.0021	-0.0019	-0.0024	-0.0004	-0.0018	-0.0012	-0.0012	-0.0017	0.0018	
1.0355	1.0100	1.0102	1.0371	1.0110	1.0090	1.0265	0.9890	0.9724	
1.0340	1.0088	1.0092	1.0355	1.0077	1.0085	1.0273	0.9894	0.9743	
-0.0015	-0.0012	-0.0010	-0.0016	-0.0033	-0.0005	0.0008	0.0004	0.0019	
	1.0359	1.0371		1.0436	1.0436		1.0115	0.9740	
	1.0344	1.0361		1.0438	1.0430		1.0116	0.9748	
	-0.0015	-0.0010		0.0002	-0.0006		0.0001	0.0008	
1.0342	1.0088	1.0110	1.0436	1.0328	1.0509	1.0363	0.9842	0.9654	
1.0334	1.0061	1.0092	1.0418	1.0308	1.0494	1.0347	0.9831	0.9669	
-0.0008	-0.0027	-0.0018	-0.0018	-0.0020	-0.0015	-0.0016	-0.0011	0.0015	
1.0311	1.0057	1.0090	1.0436	1.0509		1.0169	0.9649	0.9560	
1.0303	1.0035	1.0090	1.0416	1.0466		1.0149	0.9661	0.9566	
-0.0008	-0.0022	0.0000	-0.0020	-0.0043		-0.0020	0.0012	0.0006	
	1.0252	1.0265		1.0363	1.0169	0.9743	0.9488	0.9473	
	1.0240	1.0266		1.0324	1.0180	0.9755	0.9515	0.9505	
	-0.0012	0.0001		-0.0039	0.0011	0.0012	0.0027	0.0032	
1.0114	0.9890	0.9890	1.0115	0.9842	0.9649	0.9488	0.9403	0.9434	
1.0111	0.9875	0.9888	1.0110	0.9840	0.9660	0.9507	0.9413	0.9453	
-0.0003	-0.0015	-0.0002	-0.0005	-0.0002	0.0011	0.0019	0.0010	0.0019	
0.9764	0.9730	0.9724	0.9740	0.9654	0.9560	0.9473	0.9434	0.9493	
0.9792	0.9732	0.9737	0.9729	0.9668	0.9590	0.9505	0.9454	0.9533	
0.0028	0.0002	0.0013	-0.0011	0.0014	0.0030	0.0032	0.0020	0.0040	



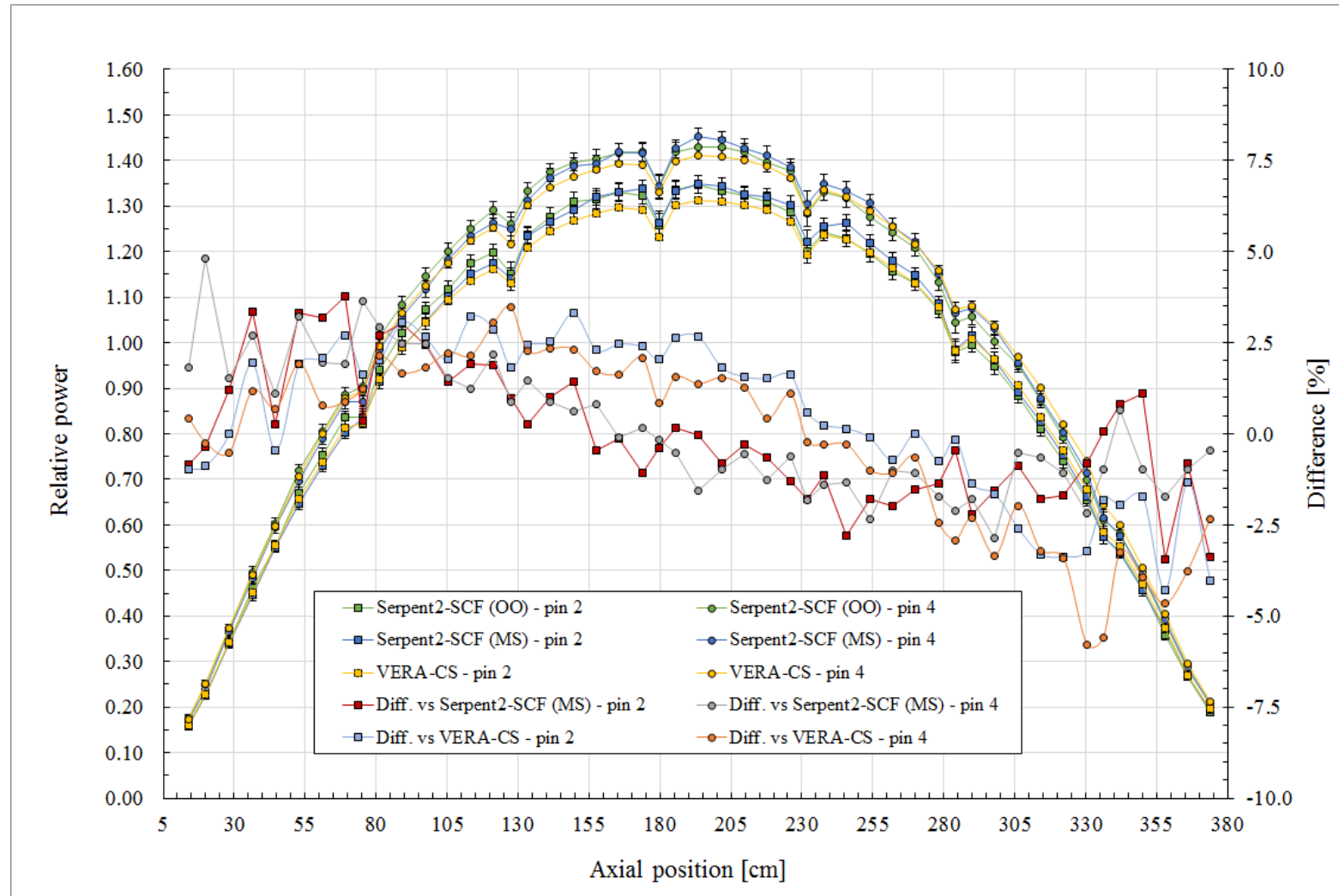
## 5 – Verification with VERA - Problem 6 (2)

- Axial power profile, integrated pin-wise:



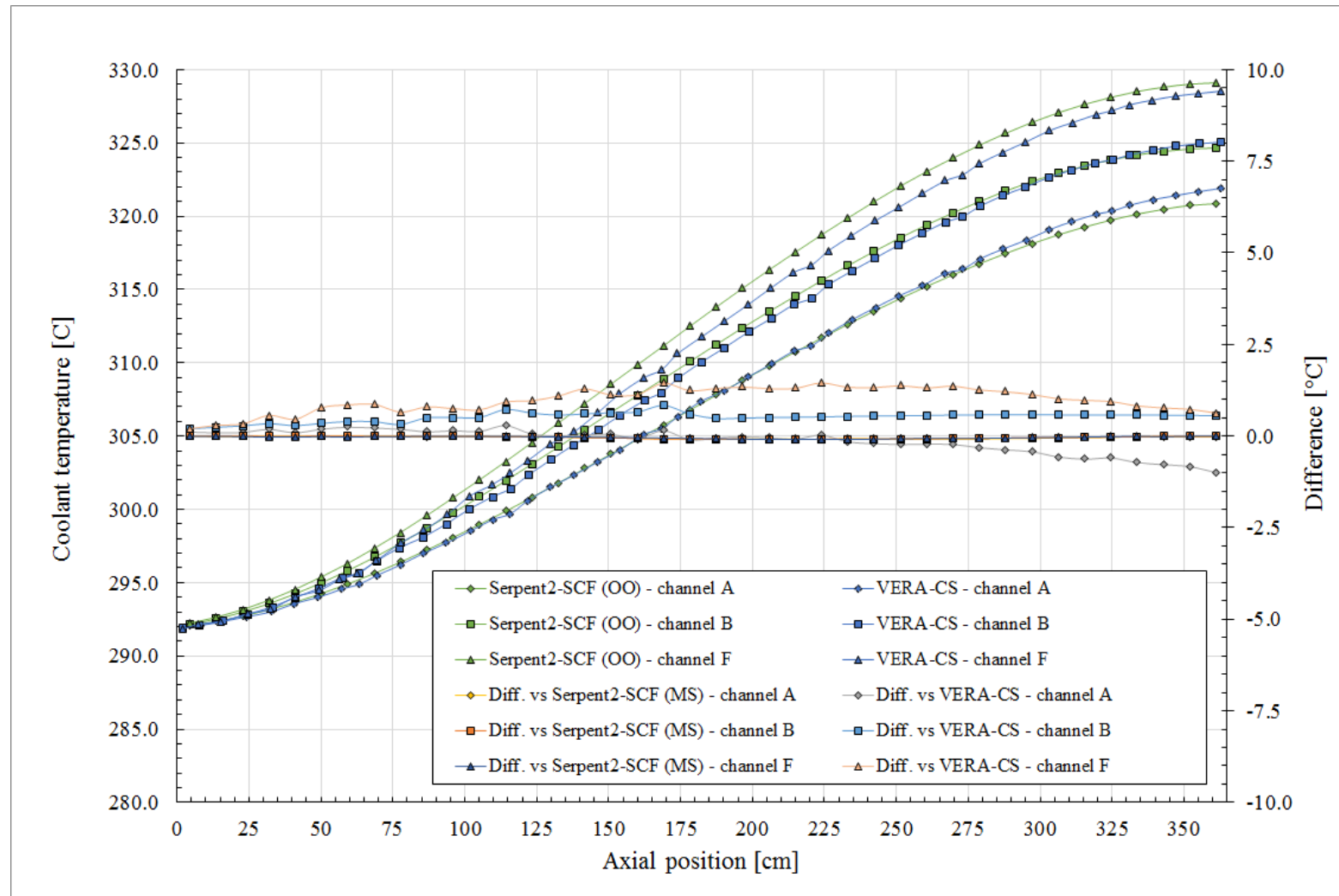
## 5 – Verification with VERA - Problem 6 (3)

- Axial power profile, for pins 2 and 4:



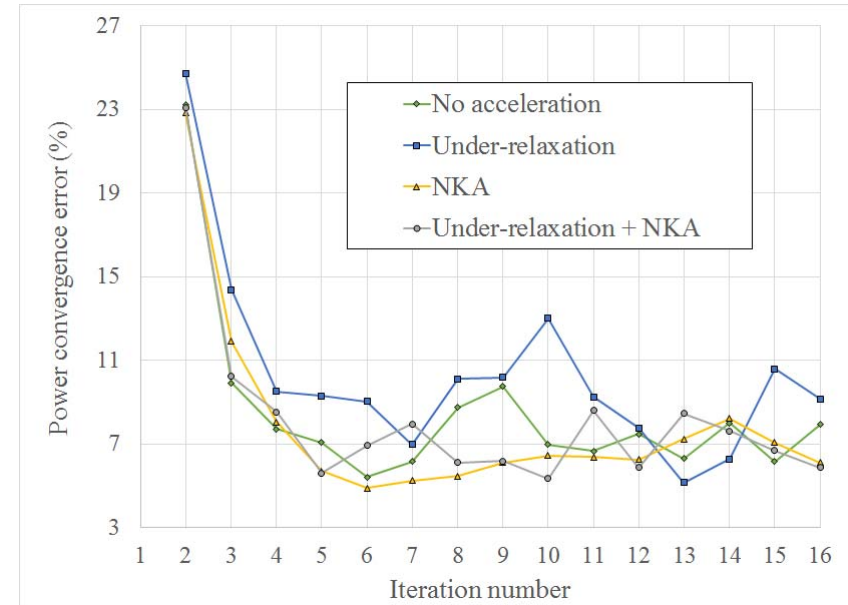
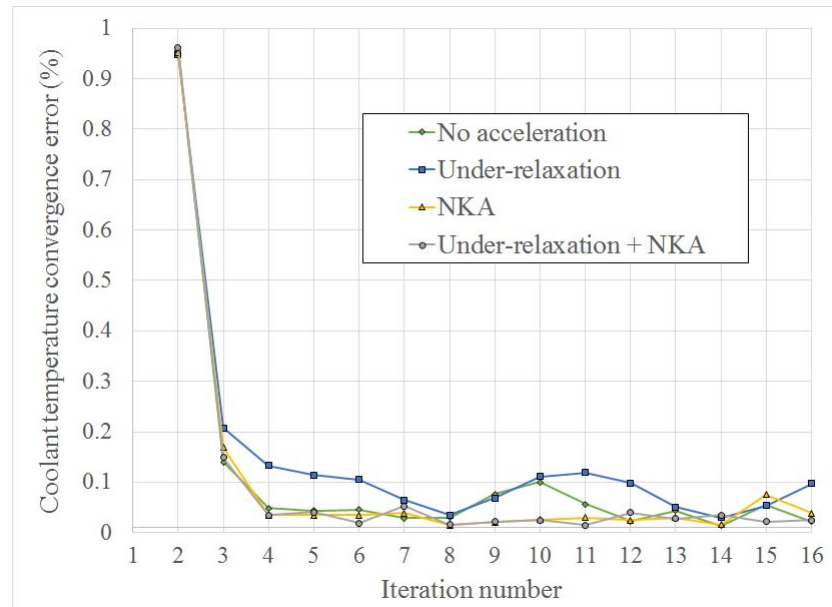
## 5 – Verification with VERA - Problem 6 (4)

- Axial coolant temperature profiles, for channels A, B and F:



## 5 – Verification with VERA - Problem 6 (5)

- Performance and convergence:
  - No significant overhead between the object-oriented and master-stave approaches.
  - Relatively small gain from using acceleration methods.
  - MC uncertainty quickly reached.





## 6 – Conclusions and further work

- Object-oriented Serpent2-SUBCHANFLOW coupling:
  - Enhanced flexibility, maintainability and code reusability.
  - Suitable for cooperation within the McSAFE project.
  - Successful verification with Problem 6 of the VERA benchmark.
  - No overhead observed with respect to the master-slave approach.
  - Geometry agnostic capabilities assessed (VVER, PWR, etc.)(see to paper ANE 135 “***Serpent2-SUBCHANFLOW pin-by-pin modelling capabilities for VVER geometries***” – M García et al.)
- Further work:
  - Towards full-core depletion:
    - Memory bottleneck → Collision-based Domain Decomposition (CDD).
    - Speedup optimization with CDD.
  - Coupling with TRANSURANUS (fuel-performance).
  - Validation with VVER-1000 and Konvoi PWR plant data.



Questions?  
Thank you for your attention!!!

# Serpent2-SCF VERA FA model

